# Thermochemical Conversion of Corn Stover

DOE OBP Thermochemical Platform Review Meeting
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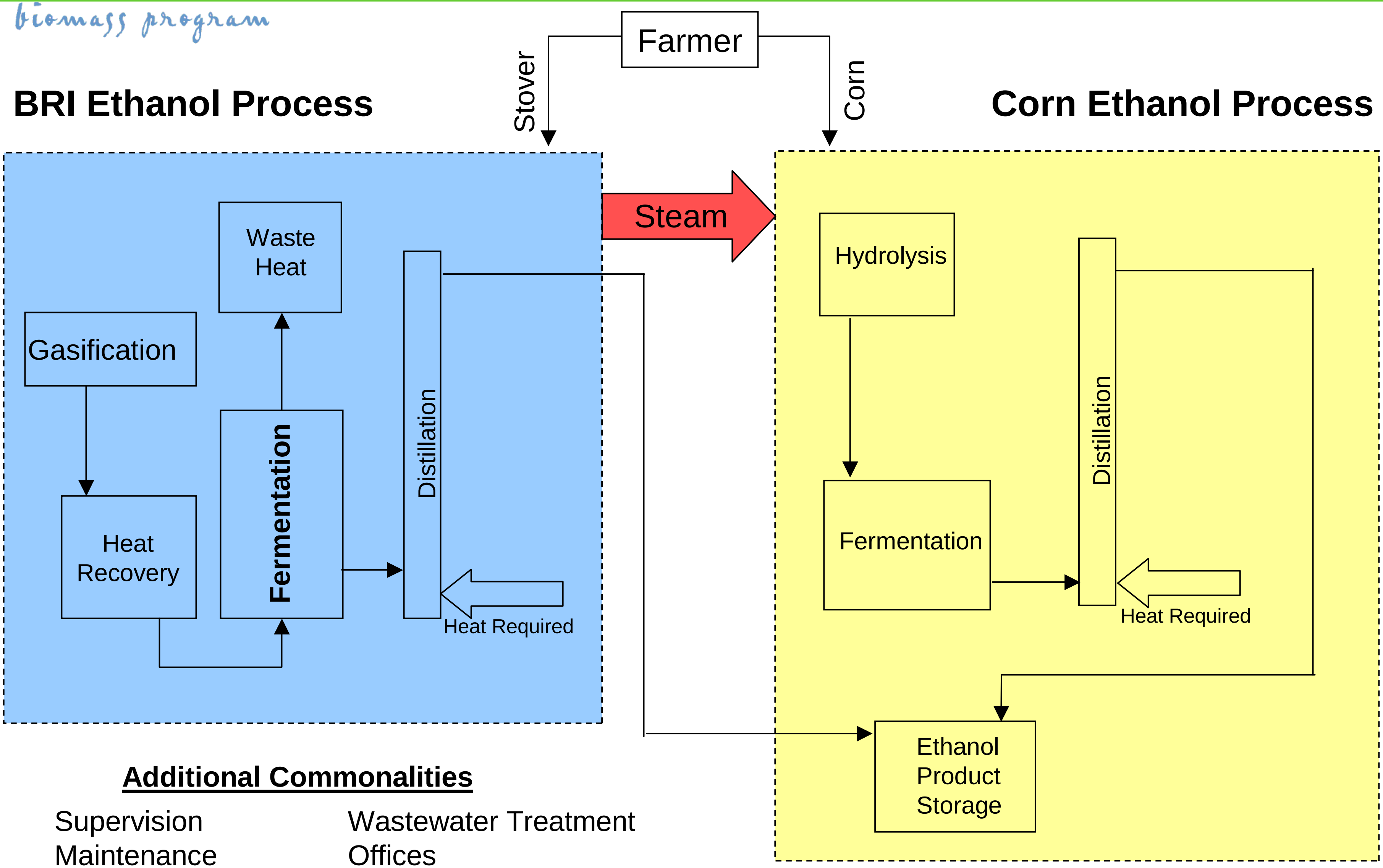
Bioengineering Resources, Inc.

# Project Background / Rationale

- BRI has been developing and optimizing gasification / fermentation technology in the laboratory and pilot plant for 15 years.
- This project was initiated October 2005 under the USDA/DOE Biomass Research and Development Initiative.
- The purpose of this project is to develop and demonstrate at pilot scale an optimal gasification / fermentation process to utilize corn stover, with emphasis placed on the integration of the ag residue ethanol facility with conventional grain alcohol processes.
- This project is in Stage 2 of the Commercial Track, of the Ag Residue Processing sector of the DOE Biorefinery Thermochemical Platform.

# Project Overview






**Additional Commonalities**

- Supervision
- Maintenance
- Security
- Wastewater Treatment
- Offices
- Others

# Pathways and Milestones – C-level and Project Milestones



**Ag Residues** | **Perennial Grasses** **Woody Crops** | **Pulp and Paper** | **Forest Products**

**Validate gasification performance**

**Validate gas cleanup, performance**

| **Project Milestones** | Type | Performance Expectations | Due Date |
|---|---|---|---|
| Corn Stover Delivery/Conditions | E | Feedstock delivery $30/ton; define optimal particle size and moisture content. | 9/06 |
| Corn Stover Gasification | D | Define temperatures to minimize tars; determine enriched $O_2$ concentration. | 9/06 |
| Syngas Cleanup | E | Determine fermentability of syngas with scrubbing and activated carbon. | 6/06 |

# Pathways and Milestones – C-level and Project Milestones



**Ag Residues**

**Perennial Grasses**
**Woody Crops**

**Pulp and Paper**

**Forest Products**

**Validate integrated production of product(s) from syngas**

| **Project Milestones** | Type | Performance Expectations | Due Date |
|---|---|---|---|
| Syngas Fermentation | D | Fermenter productivity of 50 g/L-day with ethanol concentration of >20 g/L. | 3/07 |
| Emissions Measurement | E | Meet EPA and state emissions requirements for air, ash and water discharges. | 3/07 |
| By-Product Utilization | E | Define value of ash as soil amendment and spent cells as animal feed supplement. | 1/07 |
| Design/Economics | D | Determine capital and operating costs with a 15 percent ROI at current ethanol prices. | 6/07 |

# Technical Feasibility and Risks



- Process feasibility
  - *Clostridium ljungdahlii*, the first bacterium able to convert CO, $CO_2$, and $H_2$ into ethanol, was isolated in 1989.
  - Began pilot fermentation of synthetic syngas in 2000.
  - Gasification unit added to pilot plant in 2003.
  - Successfully demonstrated wood gasification/fermentation over 15 months.  Also, MSW, ASR, cotton seed hulls for shorter runs.

# Technical Feasibility and Risks



- Process risks
  - Corn stover availability/cost.
  - Stover gasification – gas composition.
  - Stover syngas fermentability – toxins impair microorganisms.
  - Emissions cannot meet regulations.

# Competitive Advantage



- Competitive Advantage

  - Gasification provides potential for near-complete conversion of biomass.
  - Fermentation times of two minutes reduces equipment size.
  - Waste heat provides all the energy for the ethanol process.
  - Synergies with grain alcohol plants significantly reduce capital costs.

# Project Activities

Task 1. Stover Gasification
- A. Feedstock Condition
- B. Gasifier Temperature
- C. Gasification Efficiency
- D. Enriched Air
- E. Gasifier Capacity

Task 2. Syngas Fermentation
- A. Gas Clean-up
- B. Fermentation
- C. Emissions Measurement
- D. By-Product Utilization

Task 3. Economic Projections
- A. Design and Economics
- B. Energy Efficiency

# Project Team

| | |
|---|---|
| Bioengineering Resources, Inc. (BRI) | Fayetteville, Arkansas |
| Burns & McDonnell Engineering Company, Inc. | Kansas City, Missouri |
| Chippewa Valley Ethanol Company (CVEC) | Benson, Minnesota |
| Katzen International, Inc. | Cincinnati, Ohio |
| University of Arkansas | Fayetteville, Arkansas |

# History and Accomplishments

- Summary of Accomplishments
  - Stover availability
  - Stover acquisition
  - Initial stover gasification
  - Gasifier feed system redesign
  - Enriched oxygen system design
  - Preliminary operation with changes

# History and Accomplishments

## Benson, MN Regional Biomass Availability ($10^6$ dry tons)
## (1999 – 2005 Average)

| | Present Tillage Methods | Less Tillage | Total Available Biomass* |
|---|---|---|---|
| 30 mile radius | 1.0 | 1.5 | 2.9 |
| 50 mile radius | 1.4 | 4.7 | 9.5 |
| Additional marginal land | 0.2 | 1.1 | 2.0 |
| Total | 1.6 | 5.8 | 11.5 |

* - Includes grass, soybean stubble collection and wheat as a cover crop

# History and Accomplishments



## Farmers' Net Margins by Stover Collection Technique
(130 bushels/acre, $35/dry ton delivered)

| Collection Technique | Collection Radius | Margin, $/acre |
|---|---|---|
| Collect as field dried<br>baled, tub grinder | 30 mi | 3.65 |
| Collect green (wet)<br>forage harvester immediately after grain collection | 15 mi. | 19.00 |
| Collect green (wet)<br>rake fields to increase collection then forage harvester after grain collection and raking | 15 mi. | 35.48 |
| Single pass collection of ears & stalks<br>separate grain at collection center | 15 mi. | 35.00 |

# History and Accomplishments



**Corn Stover Bales**

# History and Accomplishments




**Tub Grinder for Bales**

# History and Accomplishments



**Stover from Tub Grinder**

# Anaerobic Cultures Produce Ethanol from CO & $H_2$

$$6\ CO + 3\ H_2O \rightarrow CH_3CH_2OH + 4\ CO_2$$

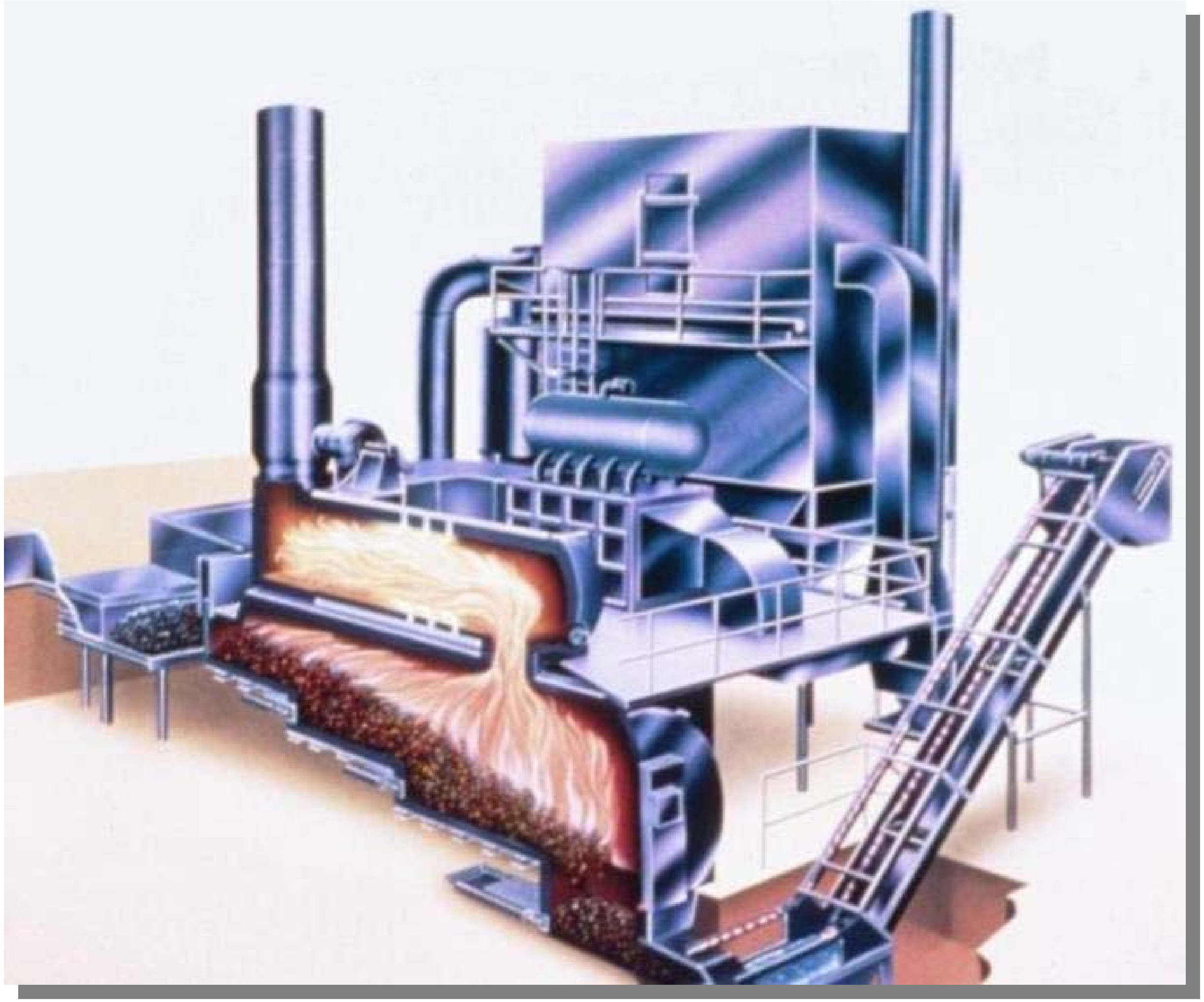
$$6\ H_2 + 2\ CO_2 \rightarrow CH_3CH_2OH + 3\ H_2O$$

# Criteria for Gasifier Selection

- Gas Quality – High CO, $H_2$
- Reliability – Continuous Operation
- Cost – Capital and Operating

# History and Accomplishments





**Consutech Gasifier**

# History and Accomplishments



**Gasification Pilot Plant**

# History and Accomplishments



**Pilot Gasifier**

# History and Accomplishments




**Pilot Fermenter**

# Pilot Gasifier Operation
## (wood)

- Particle size - 2 in. minus chips gives best performance
- Moisture content - dry (5-10% moisture) gives best gas quality
- Capacity - 1.5 TPD (design 1.2 TPD)
- Temperatures - 1000°F lower chamber best
  - 2250°F upper chamber minimizes tars

# Pilot Fermenter Operation

## (Wood Syngas)

- Gas compositions – 10-25 percent CO, 8-22 percent $H_2$
- Gas conversions – 80 percent CO, 30-40 percent $H_2$
- Reaction rate – 40-70 g/L-day
- Temperatures – 98$^o$ F
- Pressure – 0-3 atm gauge
- Variations in gas flow +/- 20 percent per hour – no effect
- Water scrubber and carbon bed adequate to remove any toxins for fermentation

# Initial Gasifier Operation With Corn Stover

- **Batch feeding on a 5 minute cycle**
- **Result was dilute gas compositions**

# To Increase Gas Compositions

- Reduce $N_2$ - Enriched and Pure Oxygen

  (Cost of $O_2$ justified by lower capital and operating cost)

- Add Continuous Feed System

# History and Accomplishments



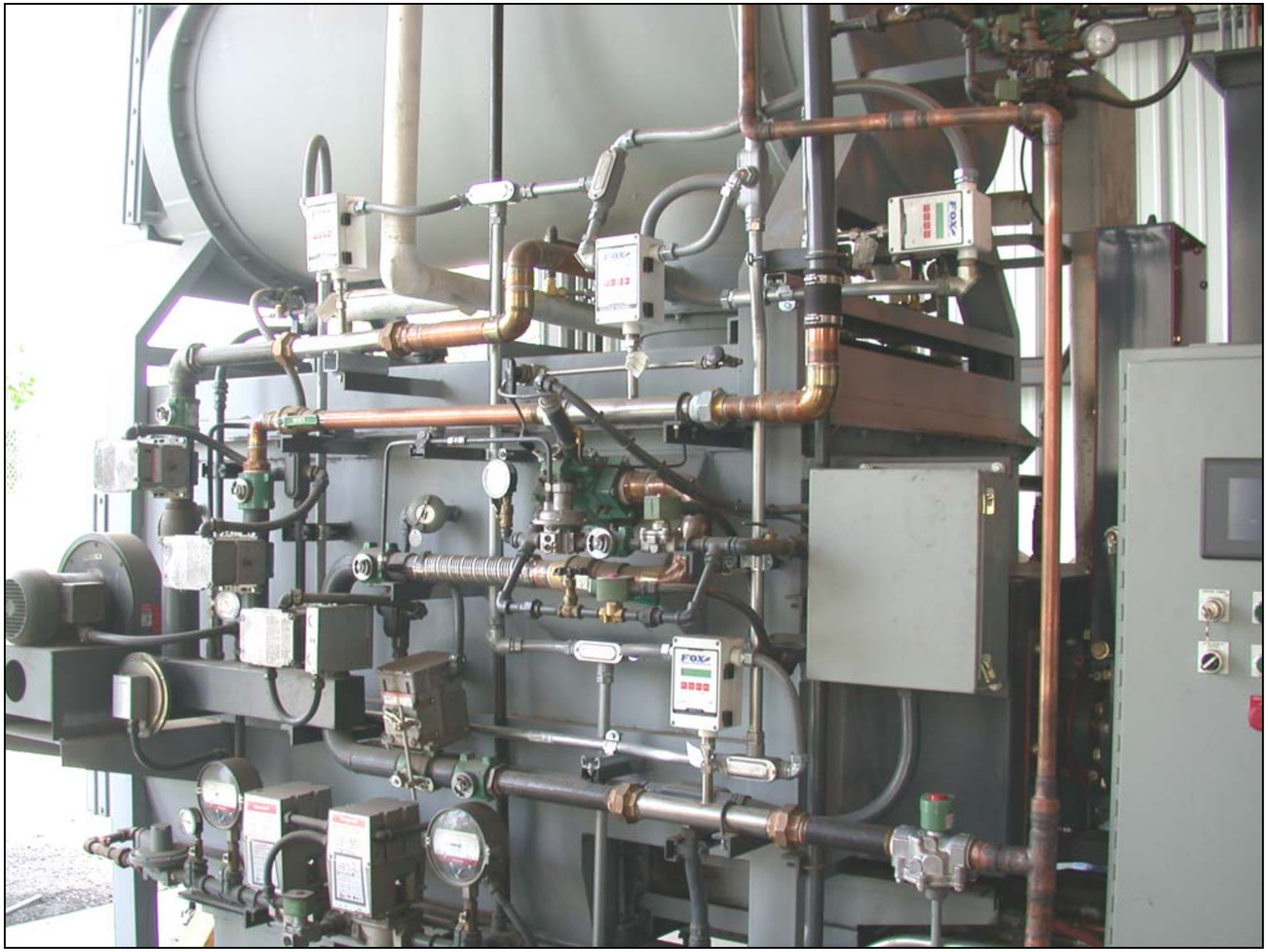

**Oxygen Supply**

# History and Accomplishments




**Pure Oxygen Controls**

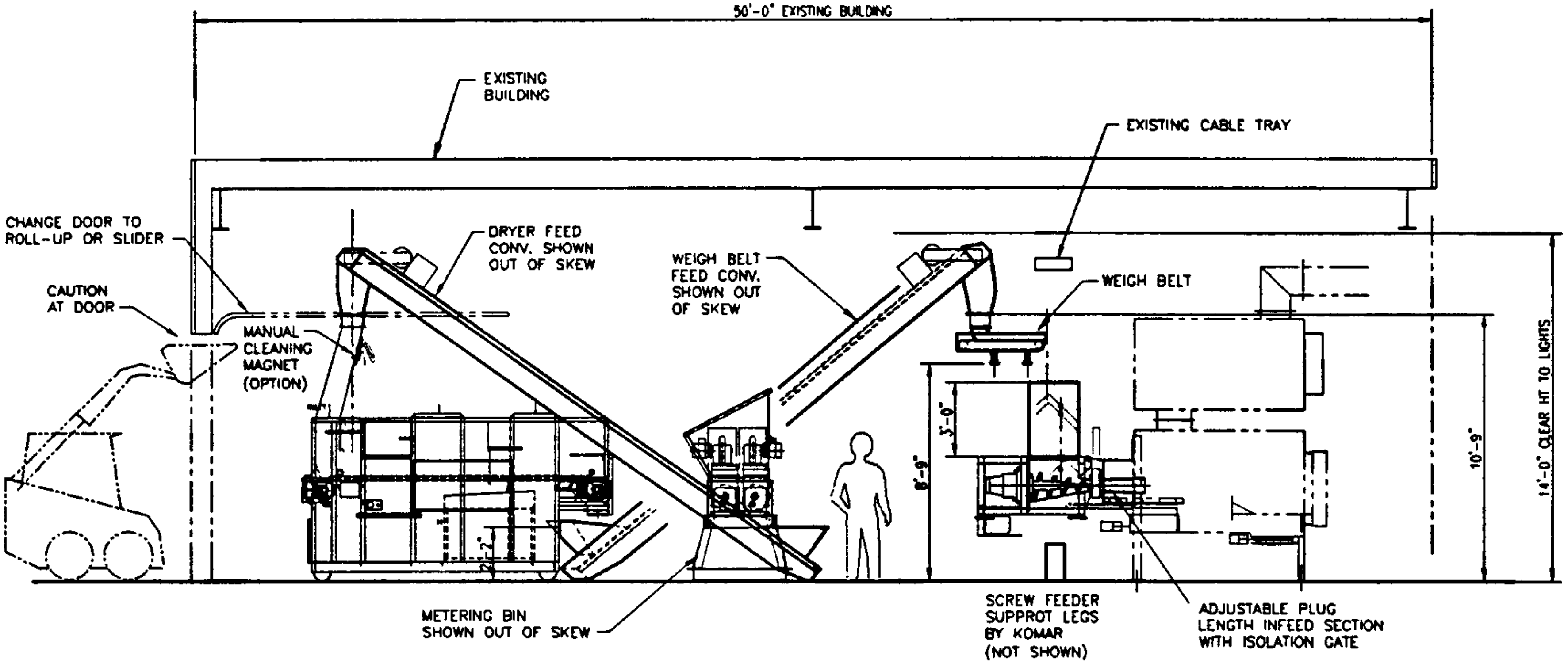
# History and Accomplishments



**Pure Oxygen Controls**

# History and Accomplishments

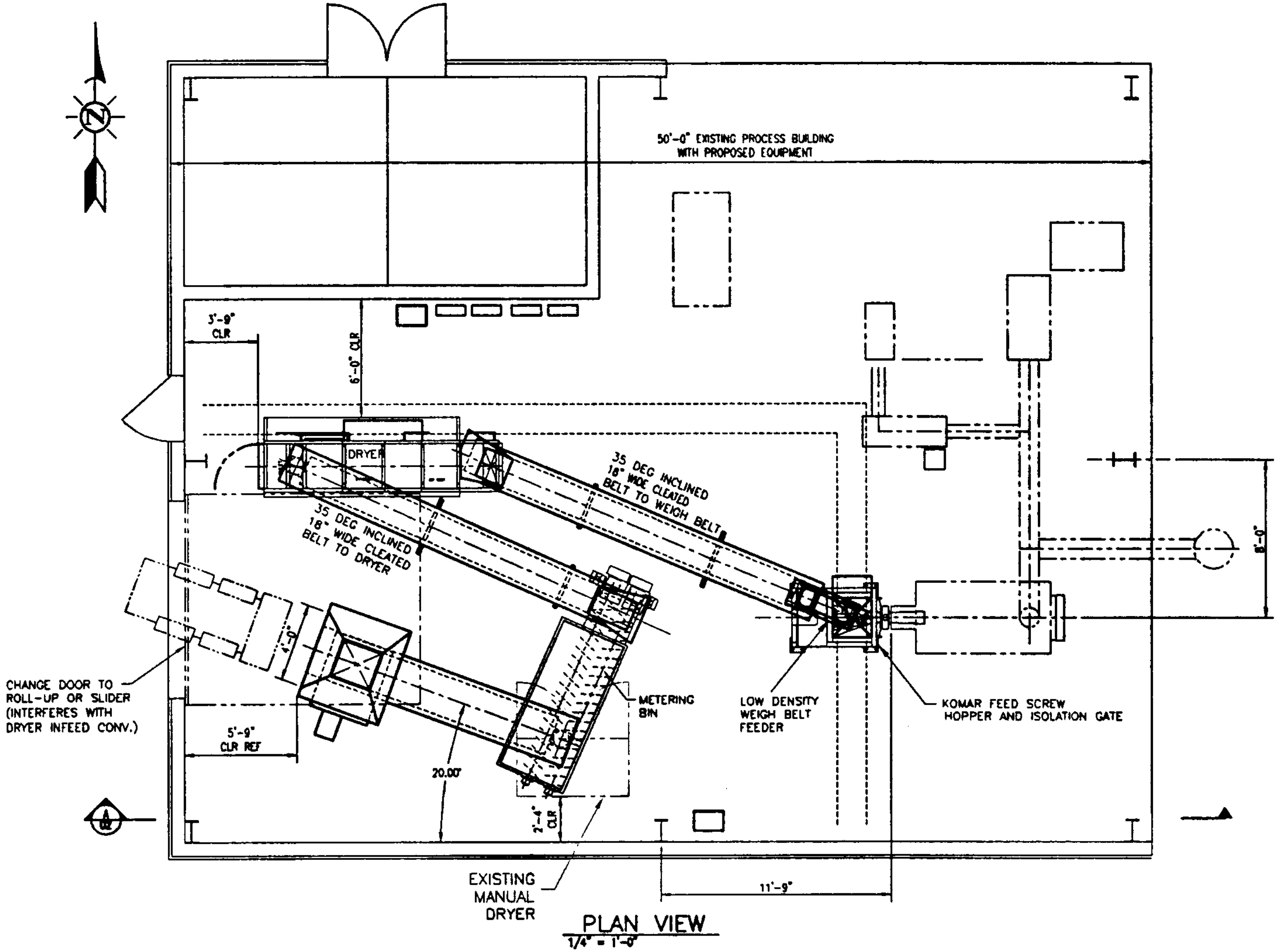





**Cross-Section View of Dryer, Metering Bin and Conveyors to New Screw Feeder**

# History and Accomplishments






**Plan View of Dryer, Metering Bin and Conveyors to New Screw Feeder**

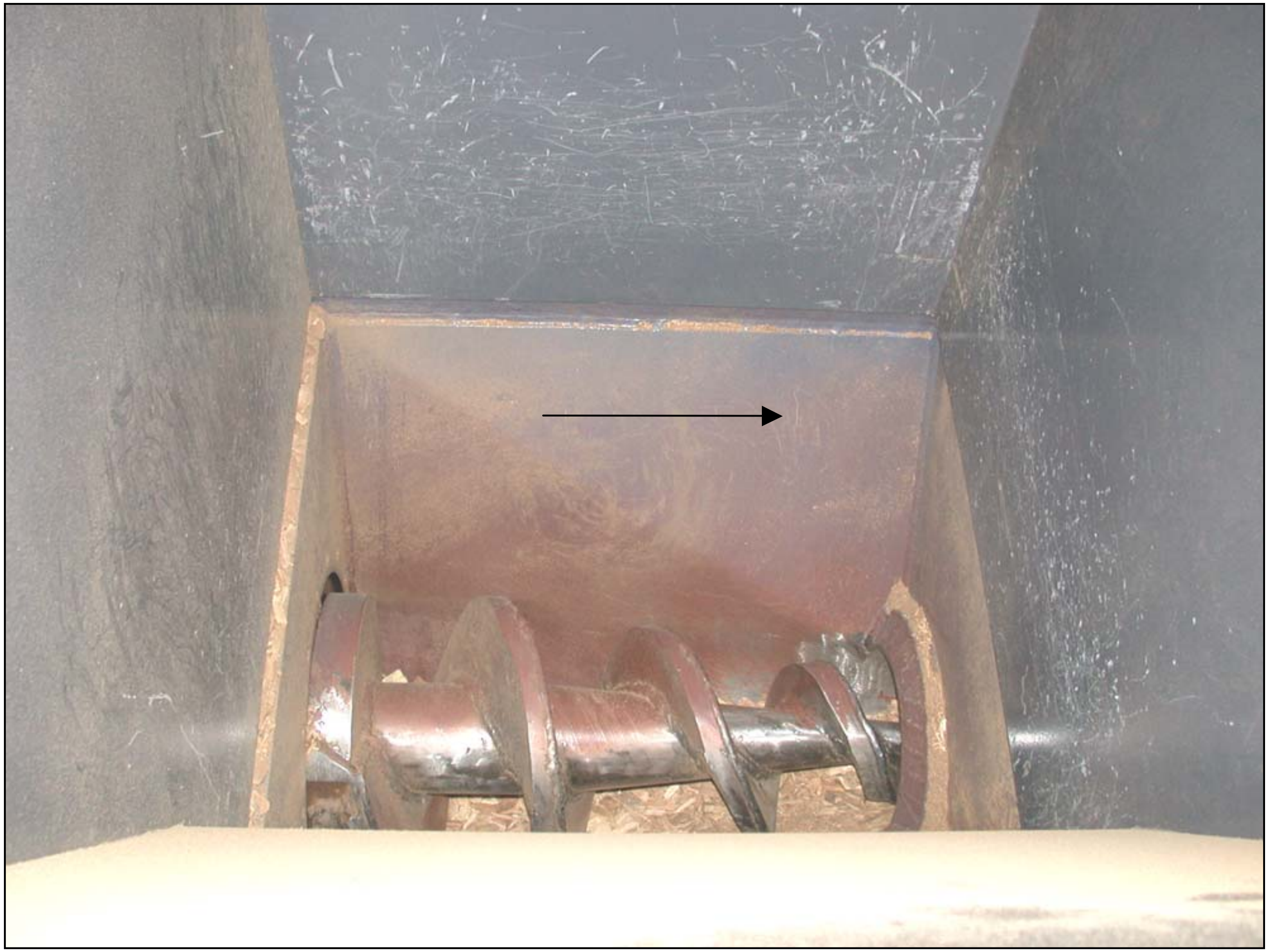
# History and Accomplishments



**Komar Feeder**

# History and Accomplishments





**Komar Screw**

# Preliminary Stover Gasification Results

Feed Rate – 138 lbs/hr (1.7 tpd)

Particle Size – 3 inch and smaller

Temperature in Lower Chamber – 980$^{o}$F

Temperature in Upper Chamber – 2200$^{o}$F

Gas Compositions

| | |
|---|---|
| CO | 20 % |
| $H_2$ | 15% |
| $CO_2$ | 37% |
| $N_2$ | 28% |

# PROJECT SCHEDULE

| ID No. | Task/Milestone Description | Planned Start | Actual Start | Planned Completion |
|---|---|---|---|---|
| 1 | Stover Gasification | | | |
| 1.1 | Feedstock Condition | 10/04 | 10/04 | 1/06 |
| 1.2 | Gasifier Temperature | 5/05 | 6/05 | 3/06 |
| 1.3 | Gasification Efficiency | 9/05 | | 9/06 |
| 1.5 | Enriched $O_2$ / $CO_2$ | 5/06 | 6/05 | 9/06 |
| 1.6 | Gasifier Capacity | 5/05 | | 9/06 |
| 2 | Syngas Fermentation | | | |
| 2.1 | Gas Clean-up | 5/05 | 6/05 | 9/06 |
| 2.2 | Fermentation Experiments | 6/05 | | 9/06 |
| 2.3 | Emissions Measurement | 9/05 | | 9/06 |
| 2.4 | By-Product Utilization | 6/05 | | 9/07 |
| 3 | Design Projections | | | |
| 3.1 | Design / Economics | 4/05 | 3/05 | 8/07 |
| 3.2 | Energy Efficiency | 9/05 | | 8/07 |

# Critical Issues and Show-stoppers

- Critical Performance Parameters

    - A syngas containing at least 20 percent CO and $H_2$ must be obtained in gasifying stover in the pilot plant.

    - An ethanol productivity of 50 g/L-day must be obtained.

    - Emissions for the process (ash, scrubber water, reactor effluent, exhaust gases) must be within State and EPA regulations.

    - Process economics must show a return on investment of 15 percent without government subsidies (other than tax credits).

# Plans and Resources for Next Stage



- Next Stage
  - Prepare detailed design for prototype stover to ethanol plant at CVEC site in Benson, MN.
    - Scale-up data from pilot plant
    - Katzen / Burns & McDonnell / CVEC produce integrated design for grain / stover facilities
  - Determine capital cost and economics
  - Build prototype

# Plans and Resources for Next Stage

- Anticipated Expenditures

| | |
|---|---|
| FY2005 | $695K |
| FY2006 | $892K |
| FY2007 | $402K |